GEOLOGY AND GENESIS OF THE STRATABOUND AND STRATIFORM CRETACEOUS-EOCENE IRON ORE DEPOSITS C EL BAHARIYA REGION, WESTERN DESERT, EGYPT

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Key words: El Bahariya, Western Desert, Egypt, Cretaceous-Eocene iron ores (ironstones)

ABSTRACT

Ironstones in El Bahariya Region are successive types of different modes, formed under subaerial and shallow marine conditions in certain places, at certain times. These types are:

1) Cenomanian stratiform ironstone confined within the upper member of the fluviomarine Bahariya Formation and cropping out as a result of wrench tectonics.

2) Stratabound iron-rich laterite hosting kaolinite and alunite nodules developed along a Cretaceous-Eocene unconformity.

3) Lutetian stratiform pisolitic-oolitic ironstone representing deposition during shallowing regimes along a Lutetian paleoshoreline.

4) Lutetian stratiform ferruginous mudstone and dolostone of restricted lagoonal conditions comprising the upper portion of the Lutetian sequence (i.e. Naqb and Qazzun Formations) in the mine areas. This ore type grades laterally, together with the underlying pisolotic-oolitic ironstone, into shallowing carbonates with Nummulite banks.

5) Stratabound karst ore resulting from paleokarstification of type 4 during a Lutetian phase of uplifting, sea-level fall and deep weathering processes.

6) Stratiform channel-fill ore conglomerates truncating the karst ore and debauching into a Bartonian sea.

7) Late Lutetian-Bartonian stratabound iron laterite developed during the intermittent lateritization of the glauconitic sediments of the Hamra Formation.

The Cretaceous-Eocene deformational history of El Bahariya Region and the related paleotopography, and the paleogeography of the Cretaceous-Eocene shorelines together with paleoclimates, and paleoenvironments, are the fundamental factors which controlled the sequential accumulation of these iron ore types at their excavated sites.

INTRODUCTION

The ultimate target of this work is to provide an integrated genetic model for the economic iron ore deposits of El Bahariya Depression which are concentrated on the northeastern plateau of the Depression at four localities, i.e., El Gedida, Ghorabi, Nasser and El Harra (Fig.1).

El Bahariya region represents one of the two main exposures of Cretaceous rocks in the North Western Desert, where the other outcrop is at Gabal Abu Roash, west of Cairo. These two localities display the highest push-up structural domains aligned along a giant tectonic line trending in an

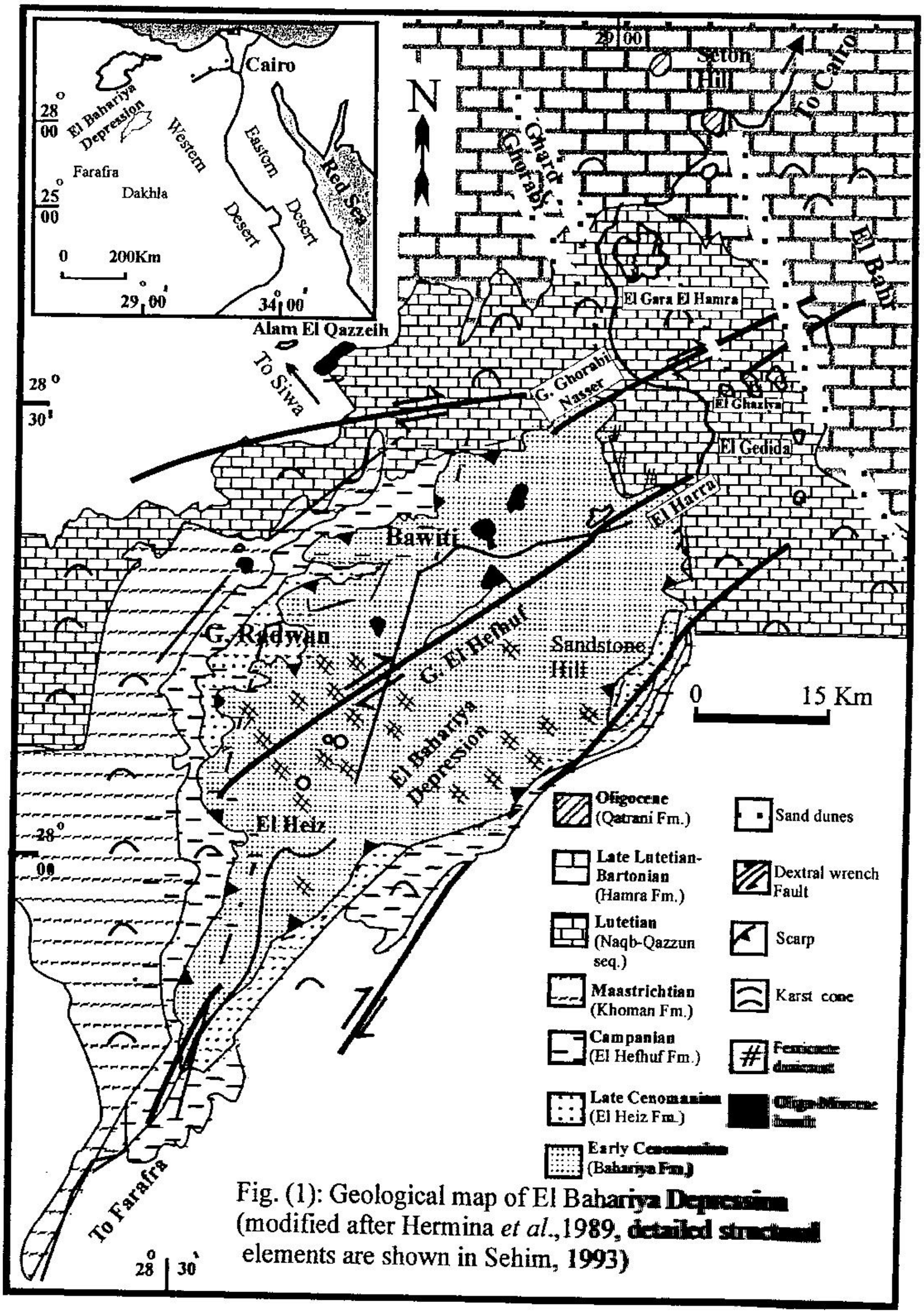


Fig. (1): Geological map of El Bahariya Depression (modified after Hermina *et al.*,1989, detailed structural elements are shown in Sehim, 1993)

ENE direction (i.e., the Syrian Arc System of Krenkel, 1955; or the Laramide movement, Said, 1990a). The associated structural elements were recently related to a wrenching stress type of regime (Sehim, 1993). The previous theories proposed for the genesis of El Bahariya iron ores were recently reviewed and discussed by several authors, among whom are: El Sharkawi and Khalil (1977), El Sharkawi *et al.* (1987), Lotfy (1988), El Aref and Lotfy (1989), Hussein and El Sharkawi(1990), Mesaed (1990), El Aref *et al.* (1991, and 1992), Khalil (1995) and El Aref (1994). These authors realized the importance of the paleotopography of El Bahariya region and paleoclimate in the formation of El Heiz lateritic (ferricrete) duricrust in the southern part of the Depression, and the accumulation of karst ore and iron laterite along the northeastern plateau of the Depression.

Owing to the complexity of the genesis of the iron deposits of El Bahariya region, the present study is focused on the following items:

1-Clarification of the stratigraphic setting of the ores and their depositional environment(s). Thus, stratigraphic and sedimentologic investigations of the ore intervals, and of the host rocks and their lateral and vertical facies changes are carried out. The importance of regional and local paleoerosional surfaces as well as marginal shallow facies is realized, as potential sites for the accumulation of iron deposits of certain types.

2-Structural analysis of the northeastern plateau of El Bahariya Depression and the included iron ore occurrences (i.e., El Harra, El Gedida and Ghorabi, Fig.1). The interplay between structure and sedimentation on one hand, and structure and unconformities on the other, are also considered.

3-Special emphasis on the geology of El Gedida mine area has been taken into consideration. The ore deposits of this area are studied in detail and classified according to their stratigraphic setting and mode of formation.

4-An integrated geologic model of the ore formation, based on the interpreted data is established.

LITHOSTRATIGRAPHY AND SEDIMENTOLOGY OF THE HOST ROCKS AND GEOLOGIC SETTING OF THE ORE DEPOSITS

The stratigraphic scheme of El Bahariya region is shown (Fig. 2). The sedimentary cover of the northeastern plateau ranges in age from Middle Eocene to Oligocene, interrupted by local and regional unconformities. In most places, this Tertiary succession truncates folded Lower Cenomanian rocks (the Bahariya Formation) and is often encrusted by surficial duricrusts, or covered by Quaternary wadi and playa deposits as well as wind-blown sands.

However, in El Bahr depression, the northeast outskirts of the investigated sector, the Tertiary succession is capped by Oligo-Miocene basaltic flows. Ironstones are confined to the following setups (types 1-6, Fig.2):

The Cenomanian Bahariya Formation

This unit builds up most of the scarp faces. It locally crops out on the plateau surfaces as minor fault blocks at only three localities: the central part of El Gedida mine area, the northwestern upstream of W. El Harra and at the western foot slopes of the Dumbbell Hill along Ghorabi-El Ghaziya fault. It is mainly formed of three members (Mesaed, 1990):

the lower mudstone-dominated member of continually prograding delta plain environment; the middle (barite-bearing) sandstone member (channel sediments); and the upper mudstone- sandstone member of storm-influenced shallow shelf environment. The transgressive episode of the upper member seems to have extended during Late Cenomanian and led to the deposition of the carbonates of El Heiz Formation beyond the northeastern plateau (Figs.1 and 2).

Stratiform ironstone bands and concretions are commonly encountered within the upper member. Most of these bands contain relics of oxidized glauconite and detrital quartz floating in a matrix of earthy goethite and hematite mixed with amorphous Fe oxyhydroxides, Mn oxides and hydroxides. The occurrence of these bands and concretions varies from place to place, but reaches workable dimensions in Nasser, north of Ghorabi area, and El Harra mine area.

The Eocene Sequences

Lutetian Naqb-Qazzun sequence

Underlying the definite highly fossiliferous marls of the Late Lutetian-Bartonian Hamra Formation, and unconformably overlying the Lower Cenomanian Bahariya Formation, is a sequence of Lutetian karstified carbonates (the Naqb and Qazzun Formations of Said and Issawi, 1964). The rocks of this sequence form characteristic cone karst landforms dominated by solution depressions and often duricrusted by thin ferricrete and silcrete crusts. In fact, in their classification Said and Issawi (op cit.) did not give a distinctive discrimination between the Naqb and Qazzun Formations or demonstrate any essential field criteria that could demarcate the contact between these rock units, except for their tones in the outcrops. Many authors followed Said and Issawi (op cit.) in considering the pink and grey tones as characterising the Naqb Formation, while the Qazzun carbonates are distinguished by their snow-white colour, chalky appearance and occurrence of silicified melon–shaped limestone concretions in the upper part of the Formation. The present field investigations could not match well any remarkable stratigraphic boundary separating this Lutetian sequence into two rock units. Also, in the studied sections (Figs.3 and 4), which were mapped by previous studies as Naqb Formation, it is found that most of the carbonate beds are white and sometimes chalky. Where the carbonates are barren or exposed to weathering processes, they are mostly masked by surficial grey or pink ferruginous tarnish. Moreover, in the mine areas, i.e. Ghorabi, El Harra and El Gedida, the Lutetian iron ores, which were related to the facies constituents of the Naqb Formation by previous authors, comprise more than one horizon, including melon-shaped silicified limestone and chert concretions with abundant moulds of *Nummulites gizehensis*. This concretionary form and the related fossil assemblage were considered as a marker feature of the top of the Qazzun Formation. Thus, the existence of these concretions within the Lutetian ore succession suggests that the latter should not be restricted in correlation with Naqb facies, but may be extended to comprise the Qazzun carbonates. To overcome the problem of stratigraphic nomenclature, which is beyond the scope of this work, the present authors dealt with the Lutetian sequence of the study sector as a single unit named Naqb-Qazzun Sequence.

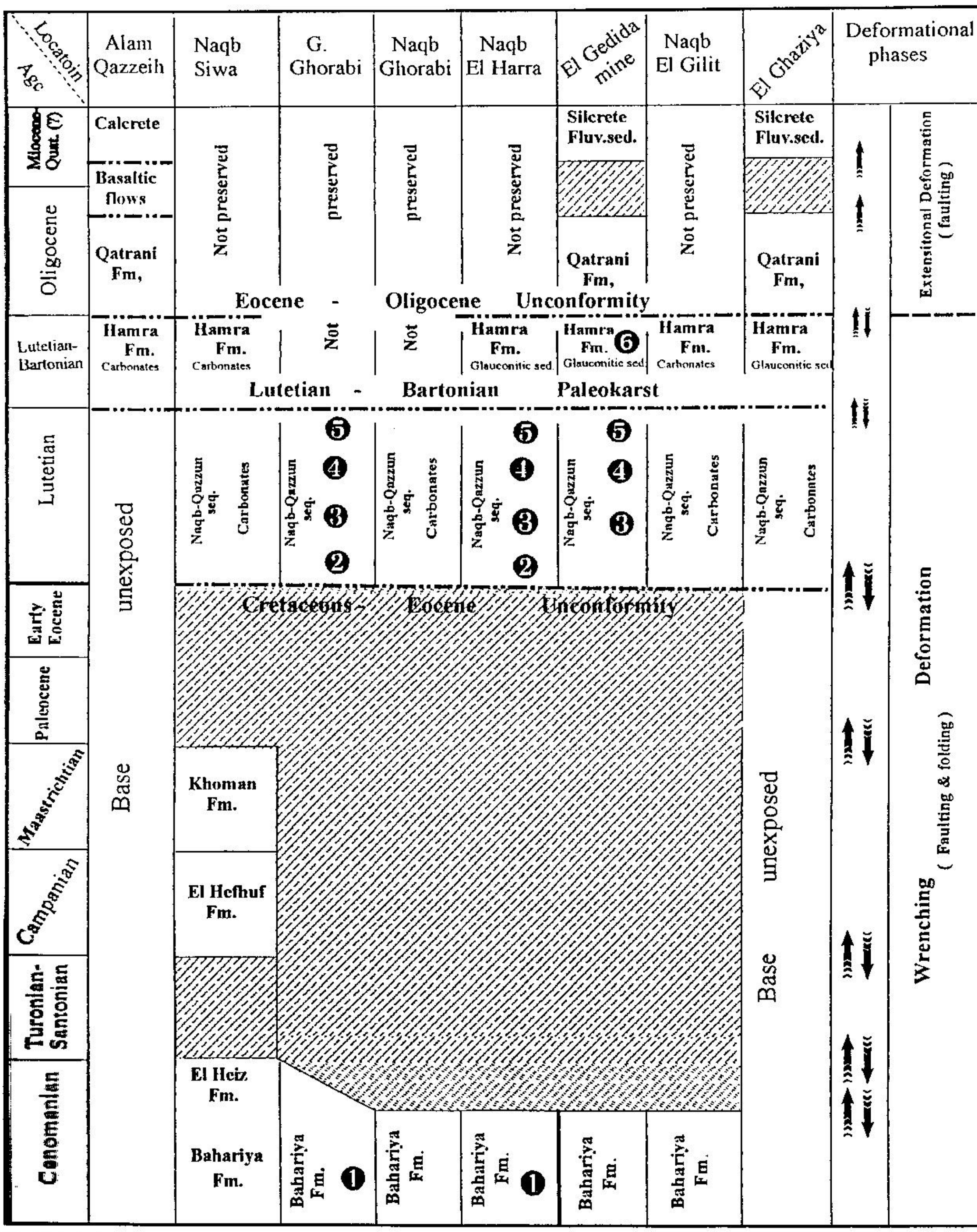


Fig.(2): The Upper Cretaceous and Tertiary stratigraphic units of the northern part of El Bahariya Depression and the related ironstone types: 1= Cenomanian ironstone; 2= Eocene- Cretaceous ferruginous latosol; **3= Lutetian** pisolitic- oolitic ironstone; 4= Lutetian ferruginous dolostone & mudstone; **5= Karst** ore & ore conglomerate; 6= Bartonian glauconitic Fe laterite.

Along the northeastern scarp face of the Bahariya Depression and Ghorabi inselberg as well as in El Gedida mine, the Lutetian Naqb-Qazzun sequence invariably truncates different levels of the folded Cenomanian Bahariya Formation. On the eastern and western scarps of the Depression, the time gap of this contact decreases, where the Lutetian carbonates are underlain unconformably by younger rock units (Fig.2). On the eastern plateau of the Depression, the Lutetian sequence overlies unconformably the Lower Eocene Farafra Formation (El Akkad and Issawi, 1963). On the other hand, the Lutetian rocks, at most places overlooking the Depression, are entirely uncovered. To the North and eastward to El Bahr depression, they are followed by discrete hills of yellow marls and limestones of the Late Lutetian- Bartonian Hamra Formation. Also, at the excavation of El Gedida mine and downstream of El Harra, the Lutetian iron ore deposits are erosively channeled and covered by glauconite-dominated facies belonging to the Hamra Formation.

The Naqb-Qazzun sequence starts with a basal lenticular bed of egg-yellow ferruginous dolostones, followed by a bed of ironstone which is slightly to intensively brecciated into shapeless rubble enveloped by stromatolitic crusts of Fe oxide (sections 1, 2 and 3,Fig.3). Laterally, moving away from Ghorabi and El Harra mine areas, and still along the scarp face, the basal unit decreases in thickness and the dolostones become less ferruginous and change into nummulitic limestone showing signs of karstification. Upward, the basal unit is followed by three similar grey to pink limestone units that are separated by irregular paleokarst surfaces along which subjacent solution channels, filled with residual Fe- rich precipitates and invariably red to dark brown matrix breccia, dominate. Each unit (4-8 m in thickness) starts with poorly bedded nummulitic and partially dolomitic and silicified limestones, grading upward into thin bedded grey argillaceous bioturbated limestone and yellow marl. These lithologies are very rich in *Nummulites* with some *Alveolines,* as well as badly preserved molluscan moulds and casts of bivalves and gastropods. In some separate intervals, the *Nummulites* are densely populated as banks. North-, east-, and southeast of El Gedida to El Bahr depression, these grey to pink limestone units change gradually into white, thick to very thick-bedded, chalky nummulitic and alveolinid limestone (30-40 m thick). The intra-Lutetian paleokarst surfaces and the associated red matrix breccia and residual precipitates which refer to diastems within the Lutetian sequence, also pinch out gradually then disappear entirely. Near the contact with the overlying Hamra Formation, the uppermost chalky beds of the Naqb-Qazzun sequence are full of *Nummulites gizehensis* with some molluscan moulds and casts. They are also characterized by the common existence of discrete melon-shaped concretions of silicified and/or recrystallized limestone, as well as crustified calcite bands and nodules of "Egyptian Alabaster" filling solution cavities and joints.

In Ghorabi, El Harra and El Gedida mine areas (sections 1,4,6,7 and 8, Figs. 3 and 4), the above-described Lutetian carbonates are replaced by a succession of ironstones of variable thickness, composed of different ironstone types of characteristic compositions, internal structures and environments of deposition (ironstone types 3,4, and 5, Fig.2). These types are, from base to top: (a) stratiform pisolitic-oolitic ironstone,(b) stratiform ferruginous dolostone and sandstone, (c) stratabound karst ore, and d) stratiform ore conglomerates.

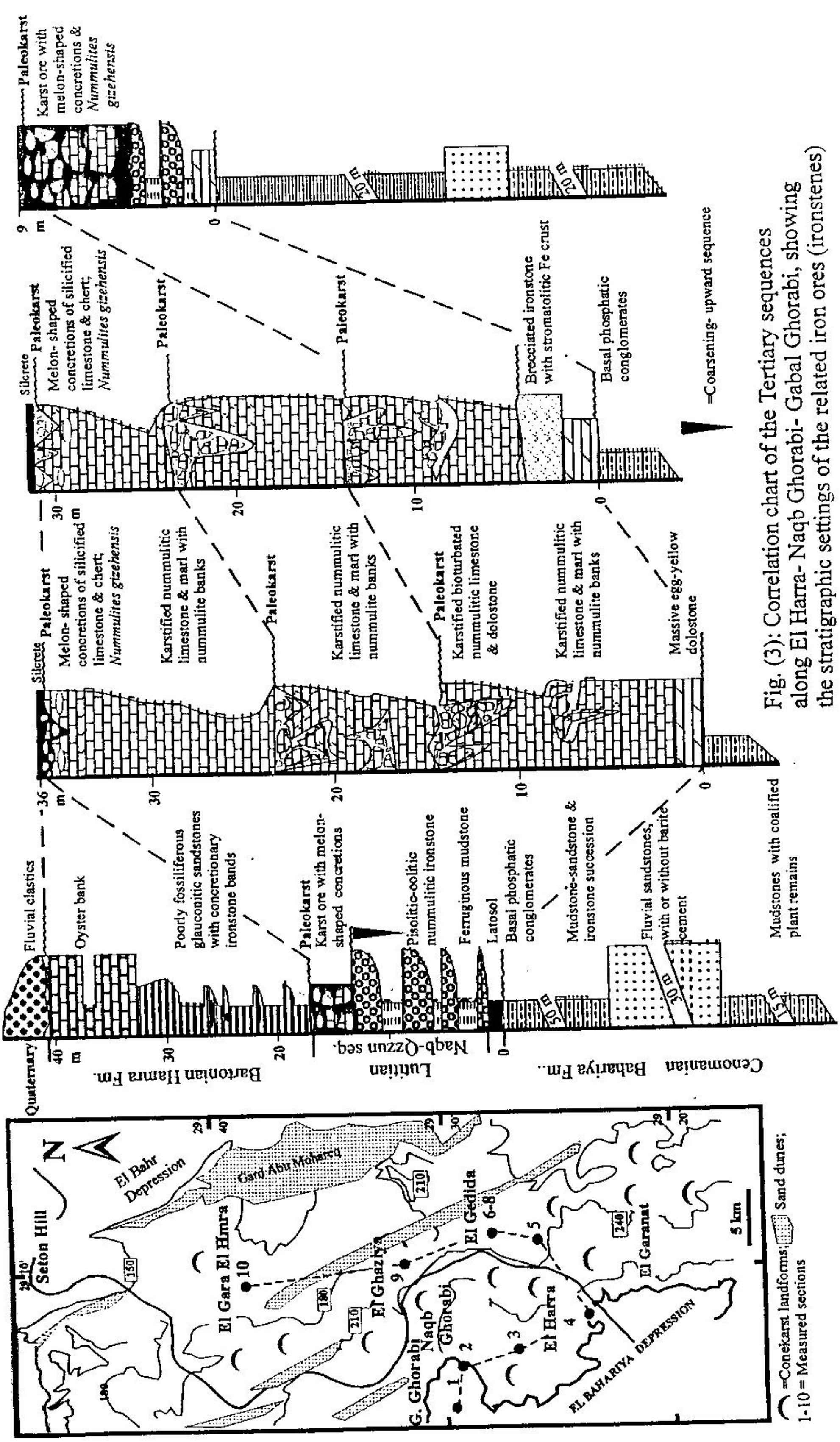


Fig. (3): Correlation chart of the Tertiary sequences along El Harra- Naqb Ghorabi- Gabal Ghorabi, showing the stratigraphic settings of the related iron ores (ironstenes)

Sedimentologically, the recognized Lutetian carbonates around the mine areas reflect deposition in a shallow shelf lagoon receiving little siliciclastic supply. The depositional regime ranges from quiet, open, circulated subtidal conditions, to highly agitated shoals. Under the quiet subtidal conditions, the bioturbated limestones and marl interbeds were deposited. On the other hand, during the shoal periods, the tests of nummulites, alveolines, other large forams and reef dwellers of molluscs were concentrated, sorted and densely packed, forming banks. However, the carbonate deposition was interrupted, particularly along and near the tectonically unstable blocks, i.e. Ghorabi, El Harra and El Gedida mine areas, by intermittent periods of subaerial exposure, associated with karstification of variable intensity and magnitude.

Late Lutetian-Bartonian sequence (Hamra Formation)

In El Gara El Hamra and northward, this unit is formed mainly of shoaling coarsening-upward sequences of fossiliferous glauconitic mudstones, marl and thick oyster banks, rich in *Ostrea multicostata*, *O.clot-beyi*, *Carolia placunoides* and *Turritella* sp.(section10, Fig.4). Southward, in El Ghaziya area (section 9,Fig.4), the Hamra Formation is divided into two units. The lower unit is built up of highly fossiliferous calcareous and glauconitic mudstone and sandstone with few marl intercalations. The upper unit is composed of poorly fossiliferous and well-bedded green sand, glauconitic mudstone, sandstone and concretionary ironstone bands and lenses. Fluvial sediments of the Oligocene Qatrani Formation channel the rock assemblage of the upper unit. Further south, in El Gedida and El Harra mine areas, the upper glauconite-rich unit is completely absent due to intensive erosion, and the Oligocene clastics rest directly above the lower unit of the Hamra Formation. There however, the lower unit, suffered further modification and facies changes. The highly fossiliferous and calcareous mudstone and sandstone facies are replaced by very thick beds of glauconitic sand with minor intercalations of kaolinitic and glauconitic mudstone, as well as concretionary alunite and lateritic ironstone bands (Fig.4). These beds truncate the underlying Lutetian iron ores, but at few places they intertongue, along the basal parts, with the ore conglomerates. Up-stream of Wadi El Harra, beds (2-8 m thick) of highly fossiliferous marl and limestone containing *Ostrea multicostata* and *Vulsella* sp are still preserved in the upper part of the glauconitic sequence (section 4,Fig.3). The stratigraphic position of these fossiliferous beds substantiates that the glauconite unit of El Gedida and El Harra mine areas is laterally equivalent to the lower clastic unit of the Hamra Formation in El Ghaziya area.The glauconite beds are apparently massive, but actually show faint planar and flaser lamination as well as few horizons of bioturbation. They are poorly fossiliferous and contain some bone fragments and shark teeth.

Sedimentologically, the above-recognized heterolithic facies of the Hamra Formation, their physical and paleontologic aspects, and the upward as well as southward tendency to be of clastic affinity, all reflect deposition under a generally regressive regime along a very shallow and open-circulated marine environment. The depositional environment was close to a continental landmass and was continuously supplied by detritus and iron mud, especially during the development of the upper unit and glauconite. The depositional

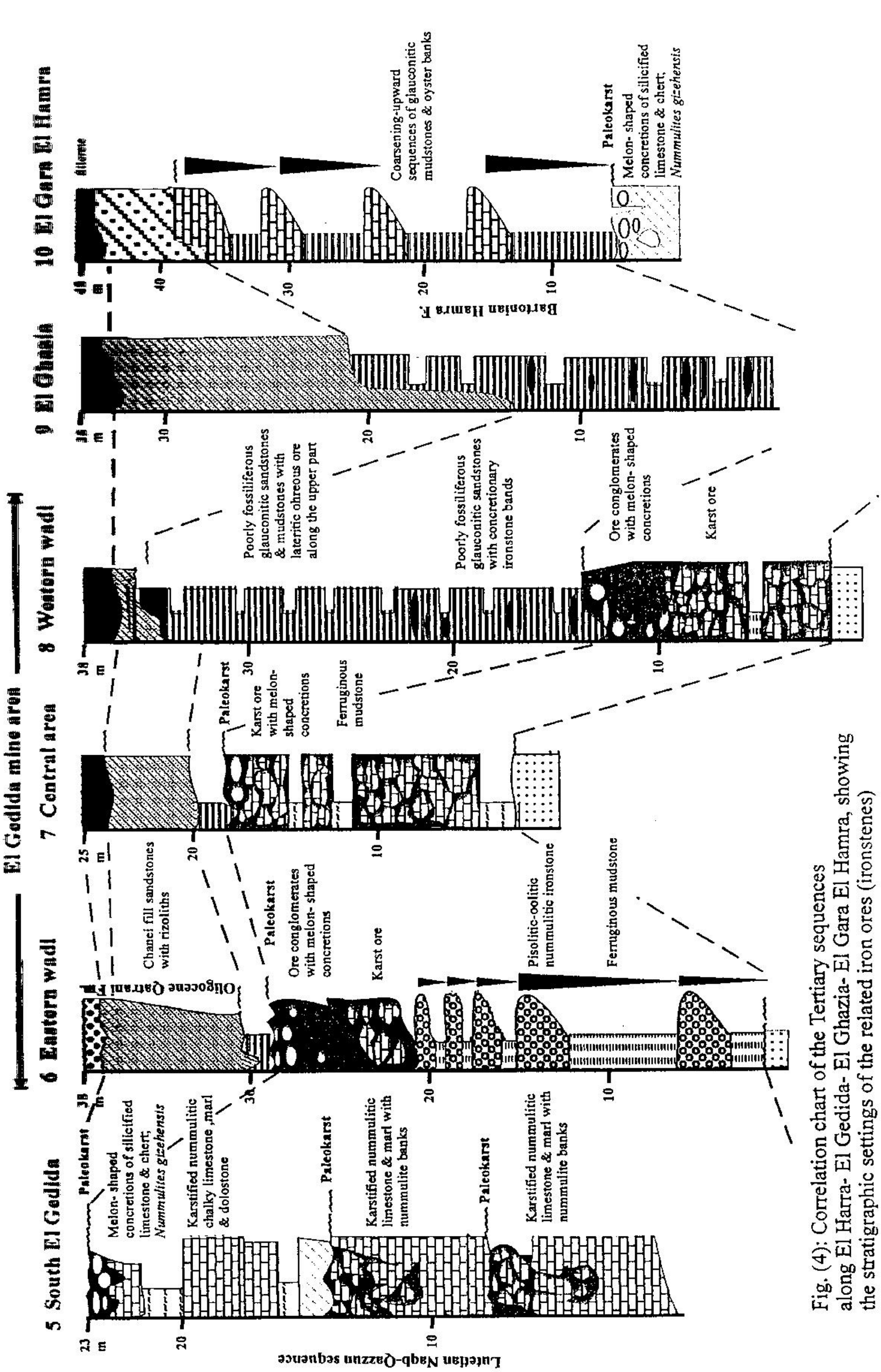


Fig. (4): Correlation chart of the Tertiary sequences along El Harra- El Gedida- El Ghazia- El Gara El Hamra, showing the stratigraphic settings of the related iron ores (ironstenes)

conditions fluctuated from quiet subtidal or sub-wave action, to a highly agitated stormy regime. Under the quiet conditions, the bioturbated marl and mud-supported limestone were laid down. On the other hand, syn-sedimentary scouring, accumulation of intra-formational conglomerates and coarse-grained clastics, as well as sorting and concentration of fossil shells into banks, occurred under the shoaling and agitated conditions. Intermittent periods of exposure and lateritization of El Harra and El Gedida blocks resulted in the oxidation of the glauconite sediments and formation of stratabound lateritic ironstones (type 6 ironstone, Fig.2).

STRUCTURAL FRAMEWORK

Detailed mapping of the structural elements of El Bahariya region (Lotfy, 1988; Mesaed, 1990; El Aref *el al.*, 1991; Sehim, 1993; Khalil, 1995; and IEP,1993-1997), revealed that El Bahariya region is much more complicated than realized earlier. The consent that this region is simply a major anticlinal structure pertaining to the "Syrian Arc System" was severely shaken after examination of the structural framework of the region (Mesaed,1990; El Aref *et al.*, 1991; and Sehim,1993). This region represents a complex deformational pushed-up domain and a system of ENE right-lateral wrench faults of delimited throw and related phases of folding (Sehim,1993). The axial traces of the associated folds make an acute angle of intersection or may be parallel to the accompanying fault. The wrenching deformation prevailed during the Cretaceous time and extended the same regime up till the Eocene, post-dating the Late Lutetian-Bartonian Hamra Formation. During the Oligocene, the tectonic style of El Bahariya region changed from compression (wrenching deformation) to extension; thus, faulting rather than folding dominated. Deposition of the fluvial sediments of the Oligocene Qatrani Formation followed by volcanic eruptions took place during the extensional regime.

As mentioned before, the resting of the Middle to Upper Eocene rocks and the associated ironstones on folded Cenomanian clastics characterizes the northeastern plateau. This may indicate that this sector represents a tectonically controlled high-stand area during the deformational phases.

One of the prominent wrench faults, cutting through the Depression and associated with severe folding on both sides of its trace, is the Bahariya mid-fault (Sehim, 1993). This fault system merges El Harra area and extends in the northeast direction to El Gedida mine. The Lutetian carbonate sequence and the associated ironstones show a deformational dip regime against the fault bounding El Harra graben, while the Late Lutetian-Bartonian Hamra Formation rests horizontally. On the other hand, the glauconitic sediments and the related lateritic ironstone are folded in El Gedida mine area and further northeast at El Ghaziya area. Also, the fault trace is clear to the east of El Gedida mine. All these features indicate Eocene rejuvenation of the Bahariya mid-fault and the related folding regimes. El Harra mine area suffered from two master faults trending in a NE-SW direction with right-lateral sense of movement. These faults mildly affect the Eocene strata with insignificant bed rotation or folding. Meanwhile, the two faults make an extended graben form in the NE-SW direction. This graben traps the Hamra Formation and the underlying ores. Quaternary playa deposits also occupy the lowland area of this graben. El Gedida mine area is one of a number of pushed up structures that are aligned along the master

NE fault. The central part of the mine area represents a major anticline plunging due southeast. This large scale folding thoroughly affects the different ore types of El Gedida mine, especially the ores of the high central areas and those of the Eastern Wadi area, which belong to the Lutetian Naqb-Qazzun sequence and the Late Lutetian-Bartonian Hamra Formation. The iron ore beds show a diagnostic fold pattern in profile view, with axes parallel to the major fold. This clearly indicates that the folding by wrenching ceased during Late Eocene time, so, the iron ores should be of Eocene age. Three fault sets are recognized (Fig.5). The most significant fault is that separating the topographically high central area from the Western Wadi area. These faults affect the ore body and the limestone plateau and form a graben trending NE-SW. The central area is delimited to the East by a N-S eastward dipping fault, while the northeastern part of the mine is controlled by a set of NNE-SSW faults dipping to the West and forming a graben trending northeast.

Further north, the northeastern plateau is affected by another giant right- lateral fault, known as the Ghorabi fault system (Fig.1). This fault system extends through the Eocene sequences to the north of the Depression. It brought the Cenomanian clastics and the related ironstone to within the plateau area in the Ghorabi mine area and further to the northeast. The fault system affected the Eocene carbonates with extensive folding along the whole fault course. On the other hand, the amplitude of the Cretaceous folds is rather greater than that of the Eocene built-up folds, indicating successive phases of fault displacements during the Cretaceous-Eocene time. The Cenomanian ironstone is thought to be preserved at shallow depths along this fault system. In the Ghorabi mine area, this master fault principally crosses the Cenomanian clastics with pronounced strain gradients, where the blocks to the north and south of the fault are strongly folded. The axial traces of these folds are oriented in NE-SW direction, as is the plunge direction. The folds form a right-stepping en-échelon pattern and the limbs facing the master fault are steeper than the others. These folds are restricted to the Cenomanian beds, and Eocene nummulitic limestones of high relief form their limbs. The Ghorabi iron ore rests horizontally on the fold area. The master fault affecting G. Ghorabi splits the Lutetian iron ore into two levels, one higher to the North occupying the foot-wall, the other lower situated in the hanging-wall.

From this discussion we can conclude that the iron ore of G. Ghorabi is over- printed on pre-existing Cenomanian and Eocene ironstones, and now appears as a horizontal surficial ferricrete duricrust, as described by El Aref and Lotfy (1989). Ghorabi area is also crossed by NW normal faults displacing the iron levels up to several meters. These faults have at least two episodes of displacement. The first phase affected the Cretaceous beds with strain rotation, while the younger phase affected the iron levels with a transitional type of regime (Khalil, 1995).

The Ghorabi fault system creates a wide wrench zone with another wrench system to the south delimiting El Ghaziya area. These fault systems dip towards El Ghaziya area, forming a low-stand area that received and preserved the Hamra Formation. This graben area suffered from extensive folding in the form of plunging and double plunging folds with fault interference of normal diagonal-slip and thrust types. The onlapping of the Eocene sequences on the Cenomanian clastics in this graben is compatible with that in the

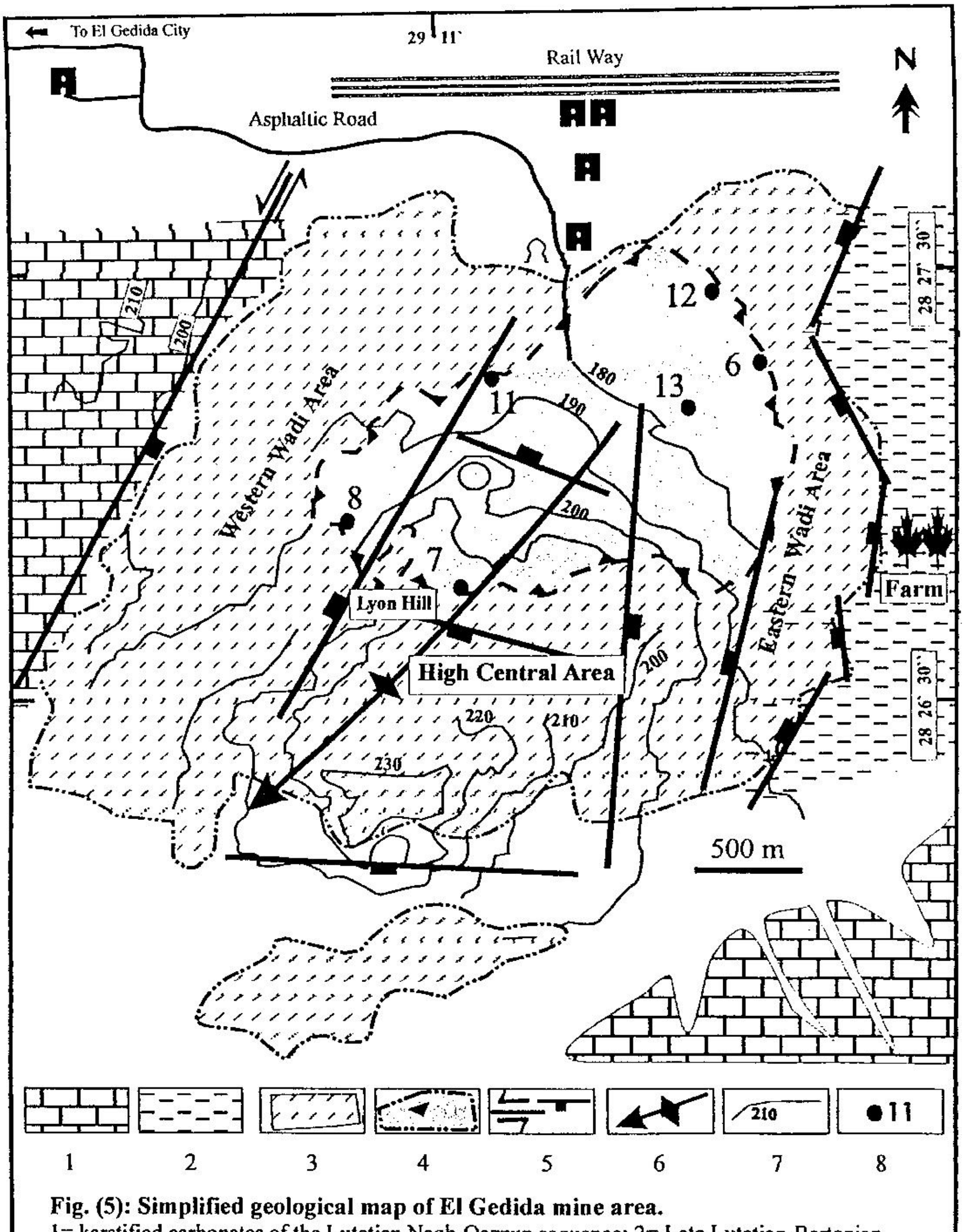


Fig. (5): Simplified geological map of El Gedida mine area.
1= karstified carbonates of the Lutetian Naqb-Qazzun sequence; 2= Late Lutetian-Bartonian glauconitic sediments (Hamra Fm.) & Oligocene fluvial sediments (Qatrani Fm.); 3= Iron ore boundary; 4= Mine working faces; 5= Fault; 6= Fold; 7= Topographic contour line; 8= Measured section

the other areas of the northeastern plateau of El Bahariya Depression. This may shed light on the long-term exposure of the Cretaceous sediments during the post-Cenomanian time span and its relation to the formation of the Eocene ores.

El GEDIDA IRONSTONES

The stratigraphic architecture of the quarried part of El Gedida mine area consists of successive stratigraphic units bound by major unconformities (Fig.6). The high Central area is built up of the Cenomanian clastics at the base, overstepped by the main Lutetian iron ore successions. In the Eastern and Western Wadi areas, the ore successions are truncated unconformably by Late Lutetian-Bartonian glauconitic sediments with lateritic ironstone interbeds of the Hamra Formation which are channeled by the fluvial sediments of the Oligocene Qatrani Formation. In the low-stand areas, Quaternary deposits often conceal the Eocene ores and the overlying glauconitic sediments. The iron ores and the overlying glauconitic sediments and associated ironstone are obviously folded and undulated. These structures refer to intra-Lutetian and post-Late Lutetian-Bartonian deformation phases, which demarcate the culmination of the NE wrench system. On the other hand, the Eocene ores and sediments together with the overlying Oligocene clastics are dissected by a system of NE-SW and locally NW dip-slip faults, related to the post-Eocene tensional regime (Fig.2).

The iron ore sequence attains its maximum thickness, up to 35m, in the Western and Eastern Wadi areas, and is much reduced in the high Central area where it attains a thickness of only 11m. This iron ore sequence consists of vertically staked specific ironstone types, including a lower pisolitic-oolitic ironstone unit followed by highly karstified-bedded ferruginous dolostones and mudstones. Ore conglomerates mixed with melon-shaped concretions and boulders of silicified nummulitic limestone and chert, overly the karst ore. These concretions are identical to those distributed elsewhere in the northeastern plateau of El Bahariya Depression along the paleoerosion surface between the Lutetian Naqb-Qazzun sequence and the Hamra rock unit. The upper boundary of the whole Lutetian ore sequence is generally of cuspate form. In some places, it is highly undulated and consists of a series of bowl and funnel-shaped pits and depressions filled with ore conglomerates. The thickness of the overlying glauconitic sediments varies from place to place. They reach up to 25m in thickness in the Eastern and Western Wadi areas, and wedge up ultimately towards the high Central area, becoming only 1m thick. These sediments are highly lateritized along several levels, giving rise to iron laterite. In bore holes No.4 and 26 (IEP, 1993-1997), the glauconitic sediments rest on highly karstified and ferruginated limestones and dolostones of the Naqb-Qazzun sequence.

Lutetian Stratiform Pisolitic-Oolitic Ironstone

This ore type is well represented in the Western Wadi area, where it attains its maximum thickness of up to 17m. Eastwards, it wedges out, becoming only 1-4m thick. It forms a fairly bedded succession consisting of small-scale, 1-3m, coarsening-upward sequences of yellowish – brown colour, and pisolitic and oolitic nature. Each sequence starts at the base with massive to slightly laminated, and pelletal ferruginous mudstone, including few nummulite moulds and goethite ooids.

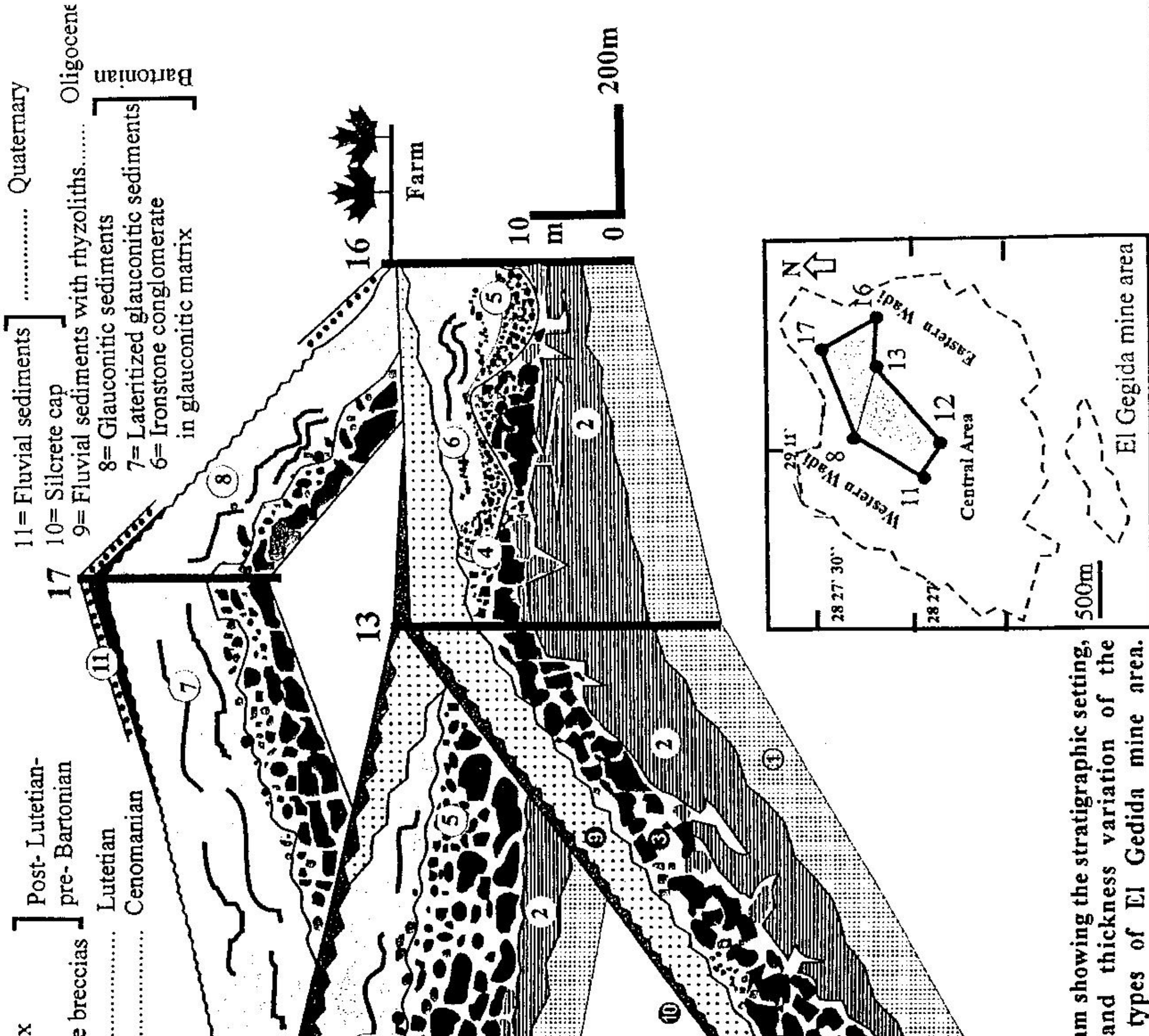


Fig. (6): Panel diagram showing the stratigraphic setting, lateral extension and thickness variation of the different ironstone types of El Gedida mine area.

Desiccation cracks, ripple marks and flaser structures are common. The basal ferruginous mudstones grade upward into a transitional bed of oolitic ferruginous mudstone, composed of a considerable amount of sand-sized goethite ooids and skeletal fragments set in an earthy ferruginous matrix. A storm-generated bed or coarse lags, up to 2m in thickness, end each sequence. The latter consist entirely of ill-sorted, grain-supported goethite and hematite pisoliths and ooids, coarse skeletal fragments, moulds of *Nummulites* spp and molluscs, and sand to pebble-sized quartz grains.

The average content of the main components of this pisolitic-oolitic ore type is (in wt %): SiO_2 (17.25-40.0); Fe (18.[illegible]-50.49); P_2O_5 (0.34-1.41); CaO (0.03-0.4); Cl (0.16-0.77); S (0.06-0.13);; MnO (0.1-0.26); Al_2O_3 (3.0-6.25), TiO_2 (0.01-0.35); Na_2O(0.18-1.32); K_2O (~0.02).

The pisolitic and oolitic nature of this ironstone type, its coarsening-upward pattern and lithologic aspects, all characterize deposition in a shoreline shoaling environment. The restricted distribution and variable thickness of this ironstone type seem to be intimately related to the paleogeography of the depositional environment with respect to nearby iron-bearing source areas as well as paleodrainage, i.e. current direction. Indeed, the deposition of ferruginous mud in localized depositional areas (the mine areas) instead of the carbonate facies, which in the meantime was accumulated in contiguous places, reveals that these local areas were probably marine depositional sites receiving debauched iron mud, weathered from nearby paleohighs. The goethitic mudstone with flat bedding and flaser lamination reflects deposition from suspension under stagnant water conditions with pulses of current or wave action. On the contrary, the pisolitic-oolitic ironstone beds suggest winnowing sorting and concentration under high energetic conditions in shoaling areas. The development of this Lutetian ironstone type on the northeastern plateau of the Bahariya Depression coincides well with the paleogeography of the Tethyan paleo-shoreline of that time, as a result of the regional northward retreat of the sea from the Early Eocene (Said, 1990a; and El Aref, 1994). Uplifting of El Bahariya region and lateritization of the hinterlands accompanied this regional northward sea retreat (Mücke and Agthe, 1988; Issawi and McCauley, 1992; and El Aref, 1994) as indicated by the development of lateritic ferricrete on the Cretaceous paleohighs (El Aref, 1994).

Lutetian Stratiform Ferruginous Dolostone and Mudstone and Stratabound Karst Ore.

These ore types constitute the main and thickest stratigraphic ore unit in El Gedida mine (up to 22m in thickness), and reflect the change from shallow marine and lagoonal environments to karst environment. The unit consists of highly karstified ferruginous dolostone and mudstone interbeds, highly brecciated and cavernous, and commonly penetrated by filled solution channels, sinkholes and large scale dolines, that are well represented in almost all of the examined mine facies (Fig.6). These brecciated rocks and associated intra-karstic precipitates comprise a characteristic breccia or enriched (illuvial) horizon, often covered by ochreous soils comprising the topsoil leaching or (eluvial) horizon of the karst profile. The karstification of the parent ferruginous dolostone and mudstone may extend down to the contact with the underlying pisolitic-oolitic ironstone type. Ore conglomerates of variable thickness, filling surface solution features and

troughs, truncate the topsoil sediments and the karstified rocks.

Relics of the intact parent rocks are recorded at some undestroyed sites, particularly along the basal levels of the karst profile, just above the pisolitic-oolitic ironstones. The most conspicuous exposure of the parent rocks is located in the high Central area, where they extend laterally for about 3 km and attain up to 15m in thickness. In the Wadi areas, they occur as disconnected bodies of variable diameters, 70cm to 5m long and 20 to 80 cm thick, within collapse breccias and residual iron-rich precipitates. They also build up the cave walls, ceilings and floors. Towards the solution features, the original textures of the parent rocks are highly obliterated.

The parent rocks comprise rhythmically alternating beds, 50cm to 3m thick, of ferruginous fossiliferous hard dolostone and softer ferruginous mudstone. They contain in (wt.%): SiO_2 (2.04-12.39); Fe (35-45); Cl (0.07-0.30); S (0.2-2.1); BaO (2-6.4); MnO (1.18-3.56); Al_2O_3 (2.07-7.3); TiO_2 (0.05). Black concordant lenticular bodies of sooty manganese (up to 18% MnO) are sometimes encountered within the ferruginous mudstone beds. Such lenticular bodies range from 1.5 to 10m in length and from 30 to 80cm in thickness, and show decrease in their manganese content towards their margins, where they pass into ferruginous mudstones.

The ferruginous dolostone lithofacies forms dense, massive and mottled beds containing 33-38% Fe. The rocks are yellowish-grey, with a dark reddish-violet tarnish on weathered surfaces. They include abundant fossil moulds of *Nummulites* sp. and molluscs, highly impregnated by iron oxides. Microscopically, the rocks consist of coarse-grained and zoned saccharoidal ferroan dolomite crystals, including prominent iron-rich cloudy inner zones and iron-poor outer rims. The ferroan dolomite rhombs are highly corroded by calcite and commonly float in poikilotopic late calcite cement. Dissolution and dedolomitization along microscopic fractures are also common. The interstitial spaces and fossil cavities are usually filled with ferruginous clays as well as globules and micro-concretions of massive or colloform goethite. Progressive dissolution along fractures is often accompanied by concentration of residual ferruginous clays and iron hydroxides, consequently leading to the brecciation of the rocks and the formation of red clasts set in a residual ochreous matrix. The intercalated ferruginous mudstone lithofacies forms nearly continuous layers that are yellow-brown, dusky red or reddish-brown, and range in thickness from 40 to 150cm. Internally, they are usually massive, and consist mostly of earthy goethite and hematite with silt-sized quartz grains, skeletal fragments and plant debris. Some of these layers are formed of nodular structures showing concentric laminae around ferruginated plant remains. Others are laminated, with individual laminae of less than 5mm in thickness. The lamination fabric is due to colour variations and slight grain-size differences. The rocks are also cut by fine veinlets filled with colloform goethite. These veinlets are confined within individual layers and usually terminate at layer boundaries.

The lithofacies association of the parent rocks (ferruginous dolostones and mudstones) suggests deposition in coastal lagoons charged with Fe-rich continental sediments. The ferruginous mudstone lithofacies suggests deposition from suspension in a low-energy lagoonal environment. Fluctuation of the supply of suspended sediments with variably sized clasts may give rise to the lamination

fabric. The earthy goethite and hematite components of this facies and the associated plant debris represent land-derived weathering products (transported soil) that debauched into the basin of deposition by surface drainage. The ferruginous dolostone lithofacies represents dolomitized lime-mud carbonates that were probably deposited in a shallow shelf lagoon or tidal-flat environment, rich in land-derived iron-rich mud. Periods of exposure and mixing of meteoric groundwater with seawater interrupted the deposition of these carbonates. These conditions were favorable for the formation of the late diagenetic coarse-grained ferroan dolomite characterizing this lithofacies.

The solution features of the enriched karst horizon include small-and large-scale subsurface openings and cavities, and near surface dolines and sinkholes. Joints, faults and bedding planes, strictly govern the distribution of these features. The intra-karstic precipitates (35-63 % Fe) comprise collapse breccia fragments embedded in earthy matrix. The soil matrix is formed of alternating, continuous and discontinuous, layers of red ochre and brick red mudstone, mixed with powdery kaolinite, rich in ferruginous plant remains and algal filaments. Fossil cavities, kaolinite, gibbsite and chert nodules are randomly scattered in the matrix. The matrix contains (in wt %): SiO_2 (1.05-3.46); Fe (53.4-59.9); P_2O_5 (~0.36); Cl (2.27-4.1); S (~0.4); BaO (0.35-1.45); MnO (1.5-1.8); Al_2O_3 (0.01-0.35) TiO_2 (~0.02). The collapse breccia fragments are also cemented by crustified concentric bands and laminae of earthy goethite and kaolinite and colloform hematite and goethite, with or without less abundant Mn oxide and hydroxide. Open fillings of Fe hydroxide and oxide also form small-and large-scale nodules, which may coalesce laterally into concretionary lenticular bodies of variable diameters. The crustified ore contains (in wt %): 55.5-58.7% Fe; 1.64-3.6% SiO_2; 0.09-0.16 % Cl; and 1.24-2.01% MnO. Speleothems containing up to 75% MnO and 8.35% Fe are often observed within some solution forms. Quartz, coarse-grained ankerite, blocky calcite, zoned barite, gypsum, anhydrite and halite are the late mineral cements.

The topsoil horizon, 0-2.5 m thick, serves as a characteristic delineation boundary between the karst ore and the overlying ore conglomerates, or the Late Lutetian-Bartonian glauconitic sediments. It attains up to 5m in thickness along the troughs of some large-scale solution basins. The lower part of this horizon, 20-70cm thick, is formed of yellow ochre which grades downward into the karst sediments. The upper part, up to 2m in thickness, is built up mainly of a mixture of nodular and rooty yellow ochre and kaolinite with finely disintegrated chert (Tripoli earth). This mixture also includes boulder, gravel, and sand-size clasts of silicified nummulitic limestone and chert. In these sediments, bedding and clast imbrication are observed in some places.

The karstification of the lagoonal parent rocks indicates a phase of emergence, most probably related to rejuvenation of the wrench system, accompanied by lowering in the sea level during which the exposed rocks were subjected to intensive karstification with accumulation of the karst ore.

Stratabound Ore Conglomerates

This ore type constitutes a stratigraphic unit, 30cm to 15m thick, unconformably overlying the irregular karst erosion surface and associated karst ore and topsoil horizon, and unconformably underlying the glauconitic sediments of the Late Lutetian-Bartonian Hamra, or the-Oligocene Qatrani,

Formations (Fig.6). It is well represented in the Western and Eastern Wadi areas, while in the high Central area, it attains a thickness of only few centimeters.
It consists of successive giant lenticular bodies, 1-5m thick, filling troughs and solution depressions, and interrupted by reactivation surfaces. These bodies show a fining-upward pattern and are made up of unconsolidated, poorly-sorted, rounded to sub-rounded ironstone (ore) gravels, reaching boulder and cobble size, floating in structureless ochres and grading upward into finer-grained ochreous precipitates. The framework components were clearly derived from the karst ore, as they consist mainly of ochreous mudstone, ferruginous dolostone, dedolomite and crustified ore containing abundant impregnated fossil moulds. Boulders and cobbles of silicified nummulitic limestone and chert are also present. Contact imbrication is frequently observed when clasts of different sizes are tightly stacked against one another. The fine-grained ochreous precipitates form continuous and discontinuous small lenses containing abundant white powdery kaolinite, black earthy Mn-rich materials, and loose ferruginous sands. Mud balls, iron-rich concretions and chert pebbles are present. Such matrix-supported conglomerates, which consist of large clasts of soft materials (iron ore), their erosive soles and fining-upward pattern, represent locally transported and rapidly dumped deposits through gravity and/or a dense flow regime. The framework components, their composition and immature textural parameters refer to their derivation from a nearby source, as a result of collapse and unorganized filling of a series of huge solution basins in the upper level of the stratabound karst ore. They are probably accumulated as fanglomerates, derived and locally transported from a high-stand iron ore source, and quickly debauched in contiguous troughs and basins.

Late Lutetian-Bartonian Stratabound Iron Laterite

This ore type is of ochreous nature, and represents soil products developed through the lateritization of the host glauconitic sediments of the Hamra Formation during times of emergence and of sedimentation. The glauconitic succession of El Gedida mine is subdivided into two successive units. The lower unit, 2-9m thick, consists mainly of folded, moderately to highly oxidized glauconitic sediments enclosing at their erosive base, lenses of ore conglomerates of variable diameters. Intensive oxidation of these sediments resulted in the formation of red and yellow ochres (30-47% Fe), including nodules of colloform goethite, kaolinite and alunite, as well as isolated irregular patches of unoxidized to slightly oxidized glauconitic sandstone and mudstone. Traces of original bedding structure can be observed. The upper unit, up to 15m in thickness, rests unconformably on both the oxidized glauconitic sediments and associated ore conglomerates of the Eastern and Western Wadi areas, and the karst ore of the high Central area (Fig.6). In the Eastern Wadi area, it consists of unoxidized, bedded green sands, glauconitic sandstone and mudstone, topped by a thin layer of paleosol, and truncated by the fluvial clastics of the Oligocene Qatrani Formation. In the Western Wadi area, the upper unit consists of the following weathering horizons which constitute the iron laterite profile:

(a) The lower horizon, 3-9m thick, consists of fresh (unoxidized), thickly bedded green sands and mudstones grading upward into the successive middle horizon. The parent rocks contain abundant bone and fossil fragments,

shark teeth, coprolites and small concretions of oxidized pyrite and siderite. Original flaser structure and ripple laminations as well as bioturbation are well preserved in these sediments.

(b) The middle transitional nodular horizon, 1-3m thick, is made up of alternating thin layers of nodular kaolinitized and alunitized glauconitic mudstones mixed with yellow ochre. The nodular layers pinch out and form horizontally arranged lensoidal bodies. The enclosed nodules are spherical and oval and consist of kaolinite, alunite and earthy goethite (El Sharkawi and Khalil, 1977). They are either randomly scattered within loose kaolinitic and ochreous matrix, or closely packed and molded against one another.

(c) The upper yellow ochre horizon, (30cm-3m), is freely drained and friable, and nearly structureless. It contains 23-54 % Fe and shows a gradational contact with the underlying horizon. Relics of unoxidized glauconite are occasionally present in this horizon. A very hard brown sheet of silcrete, 1-4m thick, caps the upper yellow ochre. This duricrust type is formed of chertified and brecciated mudstone, including abundant pockets of crustified chalcedony and opaline silica, and silicified plant remains.

The stratigraphic settings of the recognized glauconitic units as well as their thickness and lithologic variation may reflect drastic changes in the paleotopography of El Gedida mine areas during Late Lutetian-Bartonian time. Meanwhile, cyclic transgressive and regressive phases, accompanied by lateritization, prevailed.

GEOLOGICAL EVOLUTION AND ORE SYNTHESIS

The present investigations led to the classification of the iron ore deposits of the northeastern plateau of El Bahariya region into the following overstepped types, arranged from older to younger:

1) Cenomanian stratiform ironstone confined to the upper member of the Bahariya Formation
2) Stratabound Fe-rich laterite (latosol) developed along the Cretaceous-Lutetian paleoerosion surface.
3) Lutetian stratiform pisolitic-oolitic nummulitic ironstone of marginal shoaling environment, developed along a Lutetian paleo-shoreline on Cretaceous paleohighs.
4) Lutetian stratiform ferruginous dolostone and mudstone of lagoonal environment.
5) Stratabound karst ore formed as a result of intra-Lutetian paleokarstification of the ferruginous dolostone and mudstone.
6) Stratiform ore conglomerates truncating the karst ore and debauching into a Late Lutetian-Bartonian sea.
7) Late Lutetian- Bartonian stratabound Fe laterite developed during intermittent lateritization of the exposed glauconitic sediments of the Hamra Formation.

The tectonic evolution, facies and environment of the host stratigraphic sequences, as well as the paleogeography, stratigraphic setting and sedimentological aspects of each ironstone type, helped greatly in understanding the source(s) of iron and the times and places of their formation. This outcome represented the fundamental requirements for further exploration of similar ore types or sites of ore formation (IEP, 1993-1997). The formation of the recognized ironstone types is controlled by a combination of

multi-geological parameters, of regional and/or local scales, that were effective at certain times and in certain places within the framework of the geological history of El Bahariya region. These parameters include:

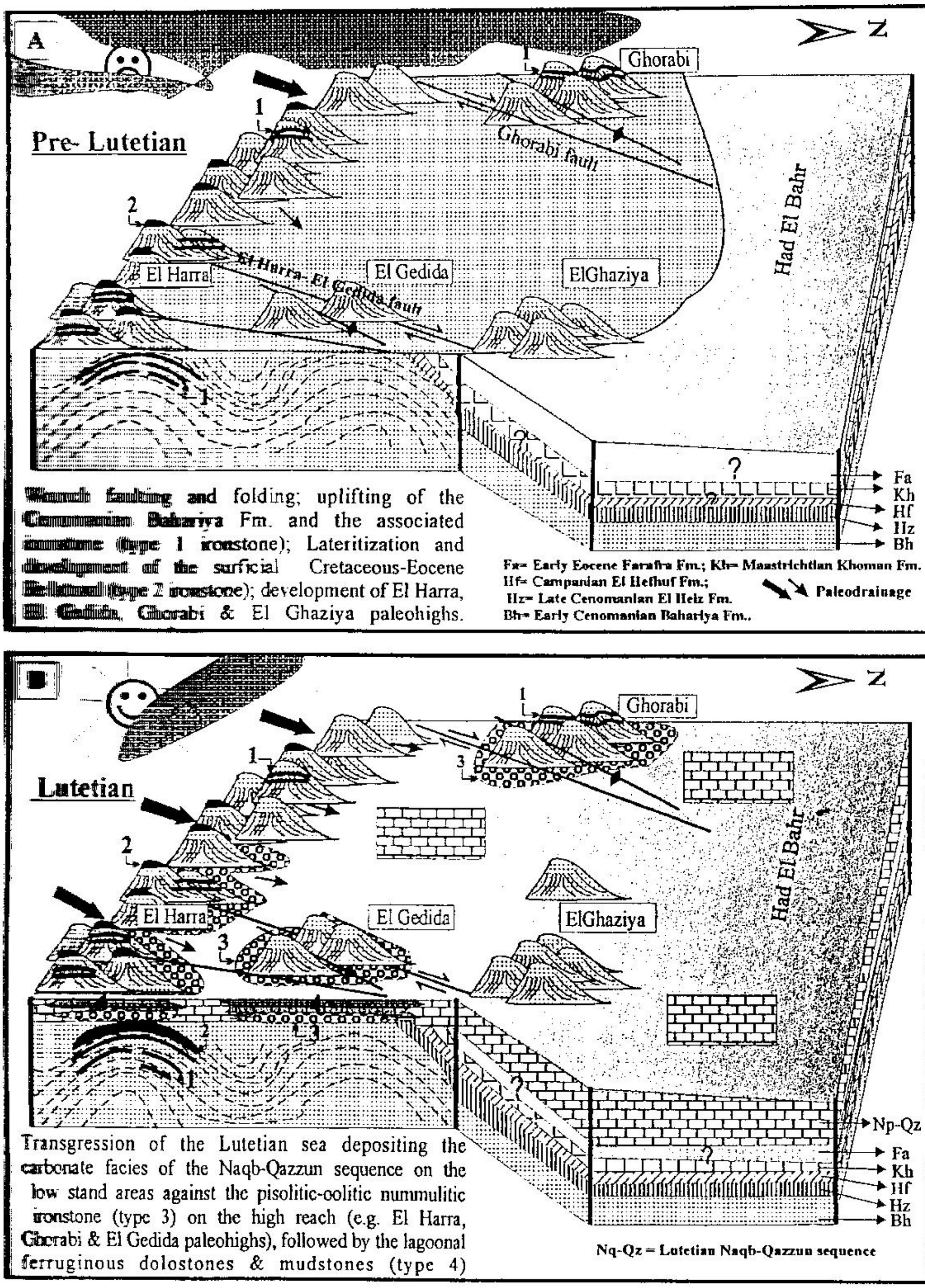
1) The paleogeography of the Cretaceous and Eocene shorelines and the adjacent erosion areas or paleohighs.
2) The paleoclimate and paleohydrology and prevalence of humid conditions during some geological periods. Humid paleoclimate was responsible for intensive weathering and lateritization of the paleohighs, with rising of the paleo-water table.
3) Paleodrainage, the essential agent for iron transportation from paleohighs to the sites of deposition.
4) Tectonic processes (faulting and folding) which controlled, to a large extent, the modification of the paleotopography and creation of restricted basins.
5) Suitable conditions of marine and non-marine or fresh water environments (physico-chemical and biological conditions) with diagenetic modifications responsible for ore formation. The Cenomanian and Eocene ironstones represent paralic facies of marine-influenced delta plain environment. A paleokarst (fresh water) environment, along an intra-Eocene paleokarst surface, led to the accumulation of the karst ore. Intermittent periods of surficial weathering of the Late Lutetian-Bartonian glauconitic sediments formed lateritic ironstone.

The following offers an insight into the geological history of the northeastern plateau of El Bahariya Depression, and the formation of the associated ironstones, in accordance with the above-mentioned geological aspects.

The development of the Early Cenomanian Bahariya ironstone can be related to: a) the updoming of El Bahariya region during the Cenomanian as a result of repeated pulses of wrench tectonics; and b) the contemporaneous creation of a marginal environment in El Bahariya region and deposition of the paralic and shallow marine sediments of the Bahariya and El Heiz Formations. The wrench tectonics created an en échelon series of Cretaceous NE-SW trending faults and folds which extend in Egypt from the El Bahariya-Farafra landstretch in the Western Desert to northern Sinai, accompanied by a general southward advance of the Cretaceous shorelines (Klitzsch and Wycisk, 1987; and Said, 1990a). The Cenomanian ironstone beds are currently hosted within the upper clastic tidal-flat member of the paralic Bahariya Formation. The wrench tectonics made high lands where the Late Cenomanian El Heiz Formation rests on the middle member of the Bahariya Formation (Mesaed, 1990; and El Aref *et al.*, 1991). The low-stand areas received a complete Bahariya section preserving the ironstone beds, e.g., El Harra and Ghorabi mine areas (Fig.7A). However, the delineation of paleolows of Cenomanian time is rather puzzling and needs further investigations.

During the Turonian-Santonian time span, the Bahariya region was positive (high) land under erosion, due to reactivation of the wrench tectonic system. This is clearly indicated by the direct resting of the Campanian El Hefhuf Formation on the Cenomanian Bahariya and El Heiz Formations (Fig.2). During the Campanian-Maastrichtian time, the sea advanced and covered a large area of Egypt including El Bahariya region. The sea became considerably deeper towards the North, depositing the carbonates of the lower part of the Sudr Formation in Sinai,

Fig. (7A-B): Schematic block diagrams demonstrating the geologic evolution of the northeastern plateau of El Bahariya Depression and the formation of the related iron ore deposits, (not to scale)



and the Khoman Chalk in the Western Desert. In El Bahariya region, the shallow marine phosphate-bearing carbonates of El Hefhuf Formation and the overlying Khoman Chalk represent the Campanian-Maastrichtian sequence. These two units are missed on the northeastern plateau, where the Early Lutetian Naqb-Qazzun sequence rests directly on elevated Early Cenomanian clastics of the Bahariya Formation.

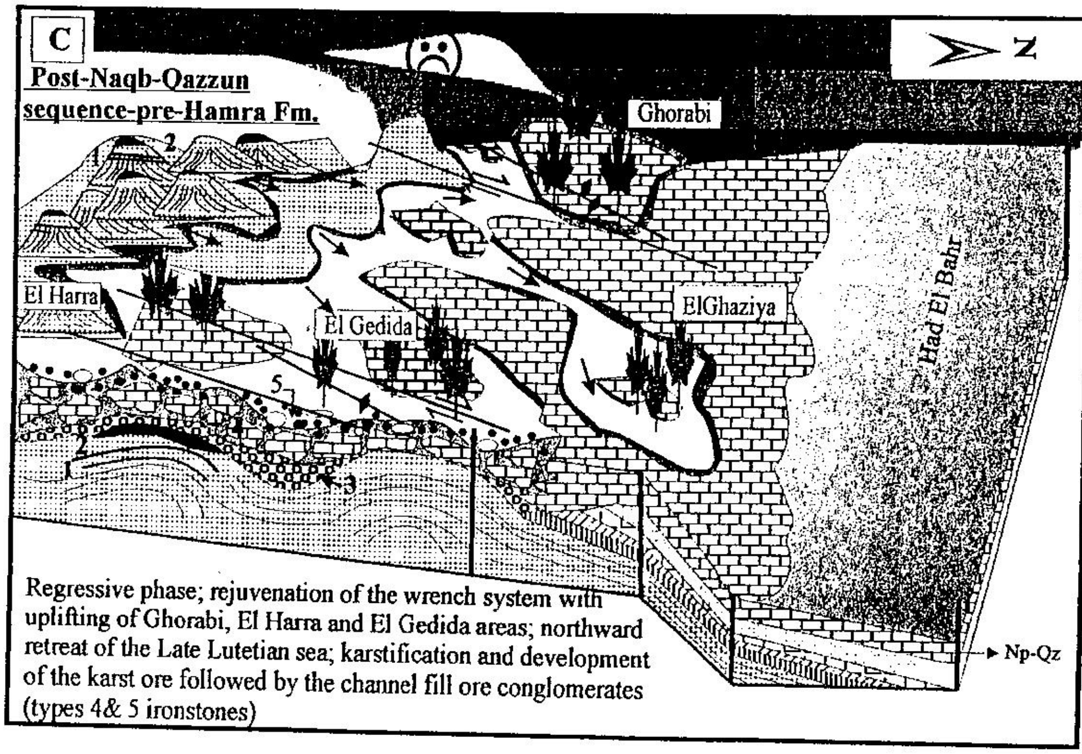
Worldwide eustatic elevation of the sea level during the Late Cretaceous- Early Tertiary led to the submergence of most of Egypt by the Tethyan sea, and consequently to the deposition of the marine shales and carbonates of the Dakhla, Sudr and Esna Formations. This transgressive phase culminated in the deposition of the Early Eocene Thebes and Farafra Formations. In El Bahariya region, the Early Eocene Farafra Formation is absent in the central part of the depression and on the northeastern plateau. Fe laterite, developed along the Cenomanian-Lutetian contact, is well preserved in El Harra paleohigh (Fig.7A).

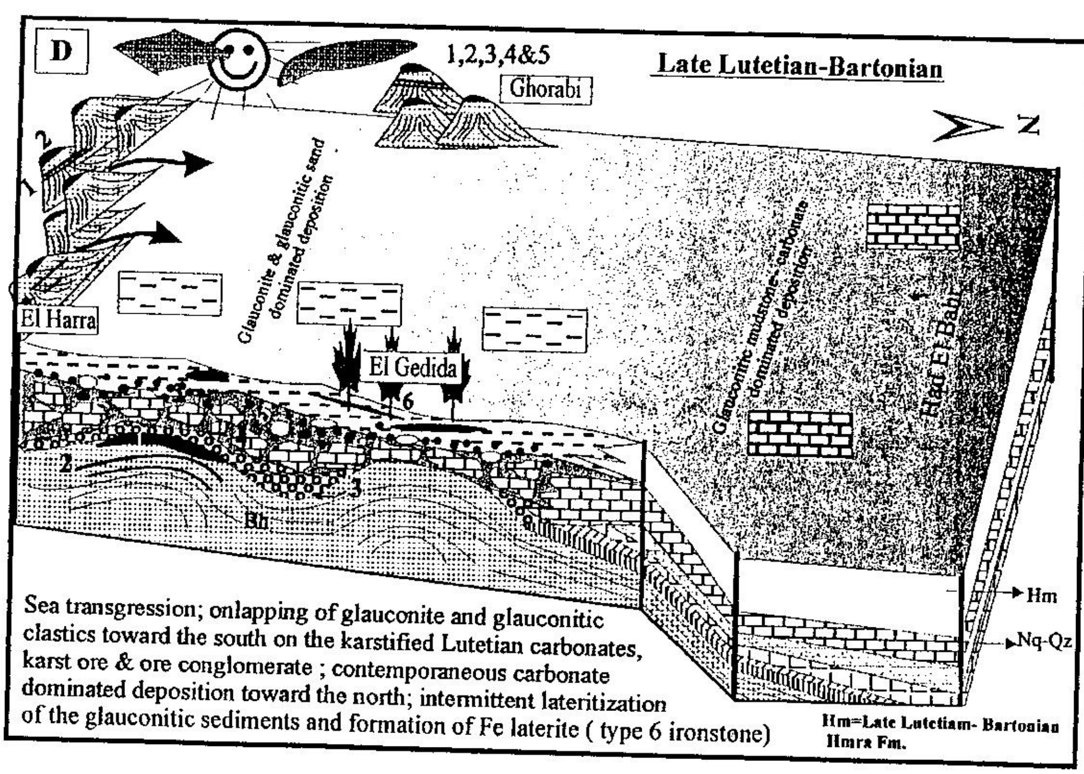
In Early Eocene time, a major northward regressive migration of the Tethyan sea started, leading to the emergence of the central and southern parts of Egypt (Said, 1990b). This regressive phase brought the Lutetian shoreline to along the latitude of El Bahariya-El Minia. Following this northward sea retreat, was the denudation-induced karstification of the exposed rocks of the southern hinterlands (Issawi and McCauley, 1992; and El Aref, 1994). Meanwhile, rejuvenation of the NE wrench system resulted in the development of a series of paleohighs and paleolows on the northeastern plateau of El Bahariya Depression (Fig.7A). It was only during the deposition of the Lutetian Naqb-Qazzun sequence that iron was replenishing, and the depositional environment was dominated by carbonates. Paleodrainage was toward the North and Northeast. The Lutetian sea deposited the main carbonate facies of this sequence on the low-stand areas, against the pisolitic-oolitic nummulitic ironstone shoaling facies on the high reaches (e.g.the mine areas, Fig. 7B). Breaks in the stratigraphy, during the deposition of this peculiar sequence, are picked out in the local development of minor paleokarst surfaces and related precipitates. These intra-Lutetian breaks indicate intermittent changes from marine to fresh water environments, during minor transgressive events or sea level falls.

The source of iron of this Lutetian ironstone is apparently the southern paleohighs, dominated by ferruginous sediments and ironstone. Fresh water charged with iron complexes and suspensions reached the shores, along which the pisolitic-oolitic ironstone facies was laid down. Iron was also introduced within the overlying lagoonal succession, and deposited in the form of ferruginous mudstone bands, or hosted in the structure of the diagenetic carbonate minerals (ferroan dolomite and calcite) constituting the ferruginous dolostone interbeds.

The absence of relics of Lutetian facies above or within the high-lying ferricrete profile of the southern part of El Bahariya Depression (El Aref *et al.* 1991, and 1992), may suggest that the lateritization processes and ferricrete formation were triggered by the northward migration of the middle Eocene sea and the associated phase of uplifting of the central and southern parts of El Bahariya region. It is also important to mention here that the Lutetian ironstone-bearing sequence is of limited distribution, and is particularly restricted to the northeastern plateau area of El Bahariya region, which was dominated by Cenomanian paleohighs.

Towards the Nile Valley to the East, the Naqb-Qazzun sequence changes into and intertongues with, the much thicker open marine carbonates of the Minia,Samalut and Maghagha Formations (Said,1990b).
The Lutetian marine Naqb-Qazzun sequence is terminated by a major paleokarst surface, separating this sequence from the overlying Late Lutetian-Bartonian Hamra Formation. This paleokarst surface indicates a major phase of emergence and sea level fall, is correlated with the equivalent unconformity surface of the Nile Valley, and coincides well with a phase of global sea level fall (Said, 1990b; and El Aref, 1994). The paleokarst event (Fig.7C) was responsible for: (a) the development of solution features filled with re-precipitated carbonates, "Egyptian Alabaster", with melon-shaped silicified limestone and chert concretions at the top of the Naqb-Qazzun sequence located around, and north of, the mine areas; and (b) intensive karstification of the interbedded ferruginous dolostone and mudstone of the mine areas, accompanied by brecciation, formation of solution features, and concentration of residual karst ore as intra-karstic precipitates mixed with melon-shaped silicified limestone and chert concretions. Channel-fill ore conglomerates truncate the karst ore.
The last paleokarst event and the associated products were followed by a phase of shallow sea transgression (Fig.7D). This regressive phase led to the deposition of oyster banks and mudstones of the Late Lutetian-Bartonian Hamra Formation on the karstified Lutetian carbonates north of the mine areas. In the meantime, direct onlapping of the equivalent coastal glauconitic sediments on the karst ore and ore conglomerates in El Harra and El Gedida mine areas took place. Lenses of the ore conglomerates are encountered within the lower part of the glauconitic sediments. During intermittent periods of subaerial exposure, lateritization of the glauconitic sediments took place, forming iron laterite deposits. The E-W facies and thickness changes appear to have taken place during this transgressive regime. The oyster banks and the coastal glauconitic sediments (up to 43m in thickness) change laterally towards the Nile Valley into the thick green shales, marl, siltstone and limestones of the equivalent Qarara Formation (up to 170m thick, Said, 1990b).
During the Late Eocene time, further northward sea retreat took place. The Cretaceous and Eocene rock sequences and the associated ironstones of the northeastern plateau were subjected to a phase of faulting and folding terminating the wrench tectonic system. Fluvial clastics of the Qatrani Formation channeled the exposed rocks. The tectonic style changed from compression (wrench system) to extension; thus, faulting rather than folding predominated. Volcanic eruptions took place during this extensional regime. Basalt sills and dykes cut across the Cretaceous and Eocene rocks of the northern part of the Depression and in El Bahr area (Fig.1). Also, volcanic lava flows (El Sharkawi *et al.*, 1994) cover the Late Lutetian-Bartonian carbonates of Alam Qazzeih area (Fig.1).
During the Neogene time span, multi-cycles of erosion involving karstification were responsible for the configuration of the present-day karst landscape of the carbonate plateau, incision of rivers, and excavation of El Bahariya Depression. Subsequent wind action modified the humid landforms and led to the deposition of wind-blown sands and sand dunes.


C
Post-Naqb-Qazzun sequence-pre-Hamra Fm.
Z
Ghorabi
El Harra
El Gedida
ElGhaziya
Had El Bahr
Np-Qz
Regressive phase; rejuvenation of the wrench system with uplifting of Ghorabi, El Harra and El Gedida areas; northward retreat of the Late Lutetian sea; karstification and development of the karst ore followed by the channel fill ore conglomerates (types 4& 5 ironstones)


D
1,2,3,4&5
Ghorabi
Late Lutetian-Bartonian
Z
El Harra
Glauconite & glauconitic sand dominated deposition
El Gedida
Glauconitic mudstone- carbonate dominated deposition
Had El Bahr
Hm
Nq-Qz
Sea transgression; onlapping of glauconite and glauconitic clastics toward the south on the karstified Lutetian carbonates, karst ore & ore conglomerate ; contemporaneous carbonate dominated deposition toward the north; intermittent lateritization of the glauconitic sediments and formation of Fe laterite (type 6 ironstone)
Hm=Late Lutetiam- Bartonian Hmra Fm.

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